Variable Complexity Structural Optimization of Shells

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Final Report

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Introduction
Structural designers today face both opportunities and challenges in a vast array of available analysis and optimization programs. Some programs such as NASTRAN, are very general, permitting the designer to model any structure, to any degree of accuracy, but often at a higher computational cost. Additionally, such general procedures often do not allow easy implementation of all constraints of interest to the designer. Other programs, based on algebraic expressions used by designers one generation ago, have limited applicability for general structures with modern materials. However, when applicable, they provide easy understanding of design decisions trade-off. Finally, designers can also use specialized programs suitable for designing efficiently a subset of structural problems. For example, PASCO and PANDA2 are panel design codes, which calculate response and estimate failure much more efficiently than general-purpose codes, but are narrowly applicable in terms of geometry and loading.
Therefore, the problem of optimizing structures based on simultaneous use of several models and computer programs is a subject of considerable interest.

The problem of using several levels of models in optimization has been dubbed *variable complexity modeling*. Work under NASA grant NAG1-1808 has been concerned with the development of variable complexity modeling strategies with special emphasis on response surface techniques. In addition several modeling issues for the design of shells of revolution were studied.

Response surface techniques:
Work on a composite cryogenic tank for reusable launch vehicle application required from the beginning the integration of an overall finite element program, NASTRAN, with a panel design program, PANDA2. Since there is substantial overlap between the capabilities of the two programs, we started with a detailed comparison of the two for a set of simple test problems (Ref. 1). Doctoral student Satchi Venkatraman found good agreement between the two programs for analysis, but substantial difference between optimization results. The differences were traced to poor derivative estimation by NASTRAN, due to an unfortunate assumption of neglecting the contribution of the geometric stiffness matrix in buckling load derivative estimation. This assumption was corrected in a later release of NASTRAN.

Next, we devised an approach to integrating both programs together. NASTRAN was used to calculate the load distribution in the tank and the global buckling loads. Derivatives of the buckling load were also calculated (by finite differences to avert the problem discussed above). The derivatives are used to create a linear approximation to the global buckling load. The loads and the approximation were then passed on to PANDA2, which was used to optimize the structure assuming that the loads are fixed and that the global buckling load is linear. The optimum design was analyzed by NASTRAN, and the procedure was repeated until convergence. This procedure was tested and showed convergence in 4 iterations (Ref. 2).

Another reason for combining various models is that the inexpensive models used by programs like PANDA2 are not accurate enough. One example is the local buckling of a ring-stiffened cylinder in compression. PANDA2 uses an approximation to calculate the local buckling load factor. In PANDA2 it is assumed that the ring stiffener deforms under the hoop load in the prebuckling analysis. In the buckling analysis it is assumed the ring does not deform. In addition, the ring attachment is assumed to be along the circumferential line at the ring locations. Comparison of PANDA2 predictions with discretized models (using STAGS and BOSOR4) where the ring stiffeners are modeled as branched shells shows that the PANDA2 model is overly conservative (by up to about 100%). In order to correct this a correction response surface model was developed. Detailed STAGS analysis was used to obtain local buckling load factors. The ratio of the STAGS to PANDA2 prediction was fitted with a linear response surface function. The fitted response surface model when used with PANDA2 was found to predict local buckling load factors to within 10%. The use of correction response surface function was shown to provide an accurate and less expensive model for use with optimization (Ref. 3). The resulting interaction with Dr. David Bushnell, the developer of PANDA2, led to a discretized shell of revolution (BOSOR4) type model introduced in PANDA2 where the ring stiffeners are now treated as branched shell elements (Ref. 4).

Modeling sandwich wrinkling:
Sandwich composite materials, in addition to their high bending stiffness, also provide increased thermal insulation. However the design of a liquid hydrogen tank with sandwich composites requires accurate failure prediction. Our investigation of sandwich panels using PANDA2 has resulted in Dr. Bushnell introducing an enhanced sandwich modeling capability in PANDA2. PANDA2 has now been extended (Ref. 5) to handle panels with sandwich construction by the inclusion of the following failure modes in addition to those already accounted for: (1) face wrinkling, (2) face dimpling, (3) core shear crimping, (4) core transverse shear stress failure, and (5) facesheet pull-off.

Preliminary design optimization of sandwich panels was performed with PANDA2. For the wrinkling load factor calculation a beam on elastic foundation type model was used in PANDA2. Since this assumes a continuum approximation for a honeycomb core, a constraint required that the half wavelength of facesheet wrinkling be greater than twice the diameter of the honeycomb cells. It was found the constraint resulted in large increase of the thickness of face sheets of the panels. A Raleigh-Ritz type analysis using discrete springs revealed that when the wavelength became small the contribution of the foundation was half of the nominal amount. Using this correction resulted in a smaller increase in weight compared to introducing the wavelength geometry constraint. Our work has resulted in changes to the PANDA2 analysis with an improved model for face sheet wrinkling at small wavelengths (Ref 6).

Design trade off studies:
In addition to this variable-complexity modeling work, several studies were performed in support of NASA design trade-off studies. First, hat stiffened and I stiffened designs were optimized for a DC-X vehicle LH_2 tank. The study has shown that hat stiffened panels were superior, but the weight difference was not large enough to compensate for the higher manufacturing cost. The study revealed, however, deficiencies in the equivalent material properties used for the analysis. This led to a study optimizing

laminate ply-lay-ups for worst case scenario, which shows that for particular laminates these errors could be as high as 200% for thin (16 plies, 0.08 inches thick) laminates (Ref. 7). Two other design studies involve the investigation of the sandwich panel concept for the liquid hydrogen tank construction, and an investigation of nitrogen purged tank wall concept. Finally, joint work with Dr. Todoroki from Japan, led to a procedure for optimum stacking sequence design using genetic algorithms (Ref. 8).

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